Test of Rectangular-to-Circular Inlet Model at NASA Langley Unitary Plan Wind Tunnel

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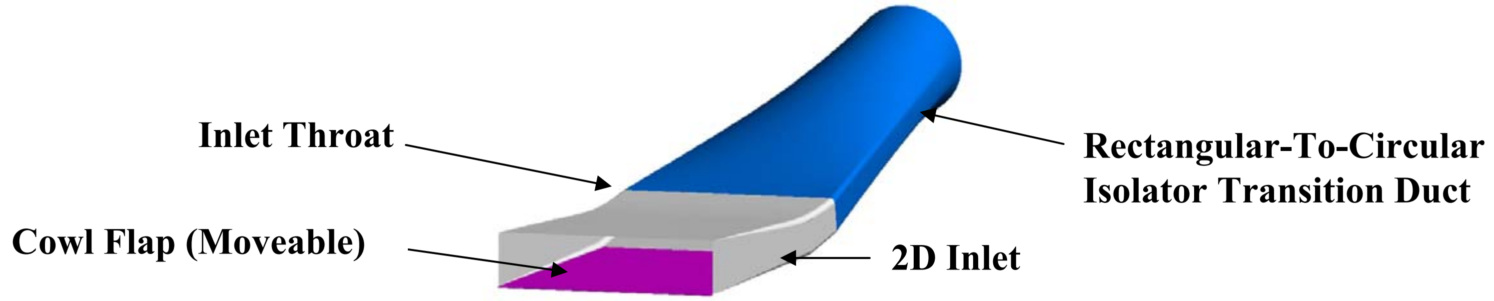
An AFRL Robust Scramjet Program project performed under contract by Alliant Techsystems and conducted in collaboration with the Hypersonics Project Office of the NASA Fundamental Aeronautics Program

Rectangular-to-Circular (RTC) Inlet Concept for Ramjet and Scramjet Powered Vehicles



- Advantages of RTC inlet concept
  - Integrates well with a 2D forebody
  - Easy to implement variable geometry (cowl flap)
  - All the geometric transition occurs aft of the inlet throat in the isolator section of the inlet
  - Circular isolator exit permits use of a circular combustor design
  - Less isolator & combustor wetted flow area (less skin friction drag and heat transfer)
  - No combustor stress concentrations with a round geometry

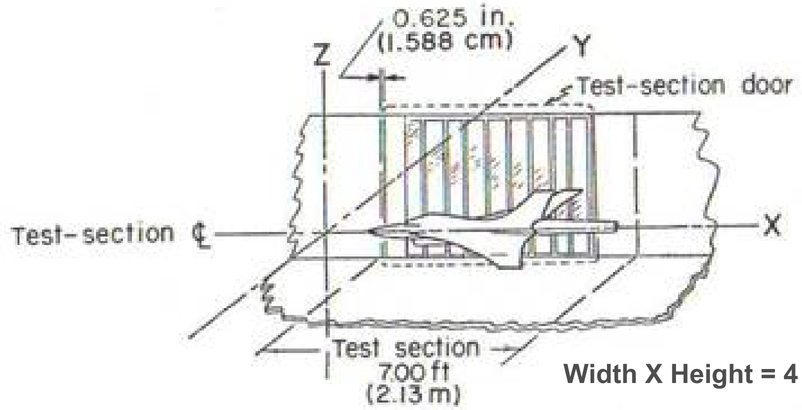
Programmatic Background

- Robust Scramjet Technology Program conceived and initiated the research effort on the RTC inlet concept
  - Managed and funded by the Air Force Research Laboratory (AFRL)
  - RST program mission is to extend the scramjet technology base from Mach 3.5 to Mach 8
- Robust Scramjet Technology contract DO-2 funded Alliant Techsystems to design and computationally analyze the RTC inlet concept with:
  - 2D forebody and internal inlet back to inlet throat
  - 2D variable geometric internal contraction (cowl flap)
  - Rectangular-to-circular transition in isolator duct
  - Maximum pressure isolation for minimum isolator length
  - Design optimized for Mach 3.5 to Mach 5 flight conditions
- Promising analytical results for RTC inlet concept led AFRL to fund Alliant Techsystems to conduct an experimental investigation (DO-3)
  - 25% scale model (selected NASA Langley Unitary Plan Wind Tunnel, UPWT, as the test facility)
  - 5 inlet/isolator configurations
- NASA Fundamental Aeronautics Program Hypersonics Project Office agreed to collaborate with AFRL on this effort
  - to fund UPWT test costs in excess of $100K
  - Provide hypersonic airbreathing propulsion test expertise
  - HYP.03.01: HYP Propulsion - Partnerships

UPWT Test Objectives for RTC Inlet Model

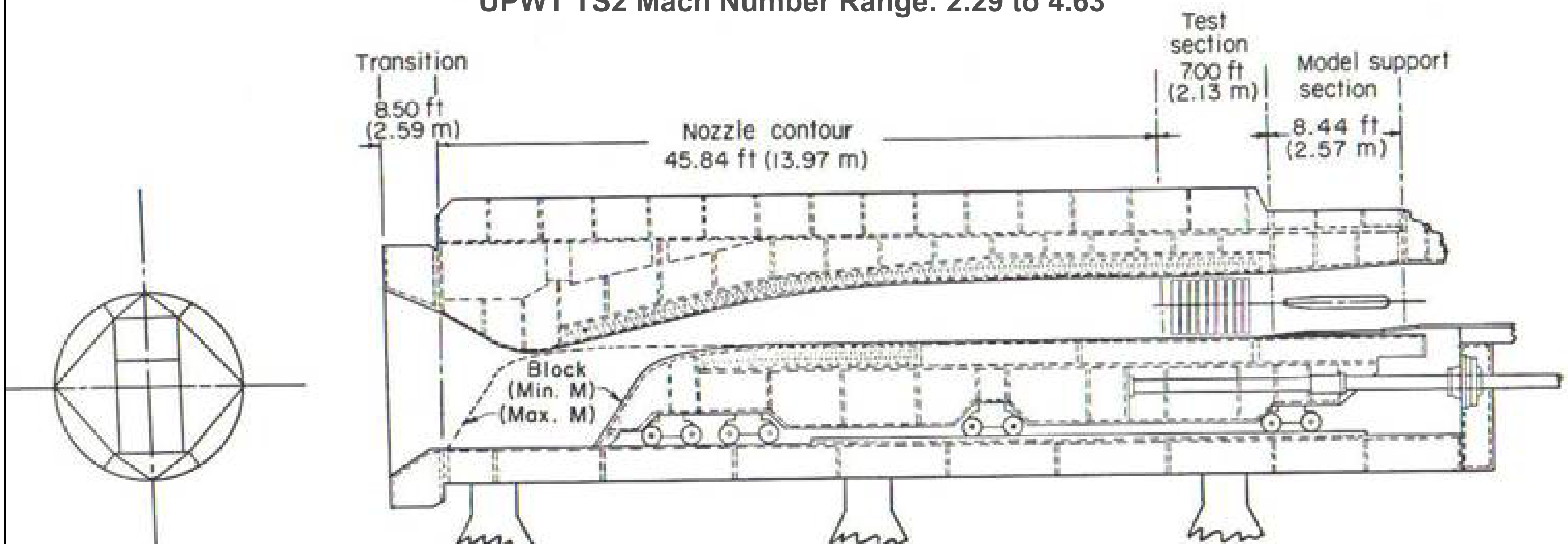
- Body and cowl side pressure distributions for:
  - an unstarted inlet
  - the internal contraction ratio (ICR) and back pressure operability limits
  - for selected ICR and back pressure settings below the operability limits
- 2D inlet drag from model centerline pressure integration
- The maximum inlet pressure rise (p_{max} / $p_{inlet\ entrance}$).
- Flowfield survey pitot pressure profiles
  - model leading edge
  - inlet cowl leading edge
  - isolator exit plane
- Inlet/Isolator total pressure recovery
- Inlet mass capture versus inlet ICR
- Inlet maximum ICR limit before unstart (with and without back pressure)
- Maximum back pressure limit before unstart versus inlet ICR

NASA Langley UPWT Test Section 2

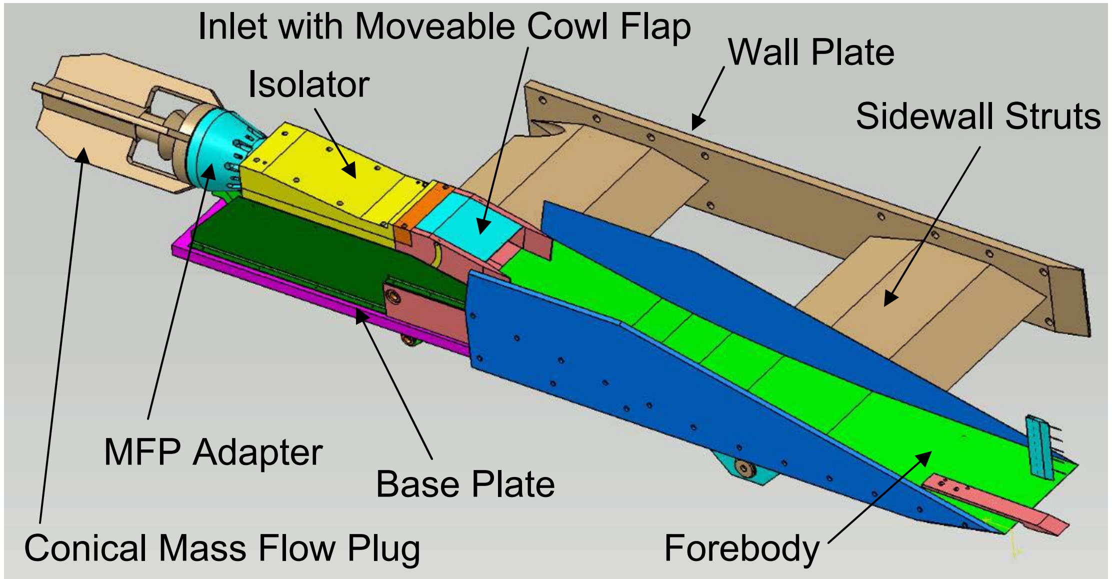


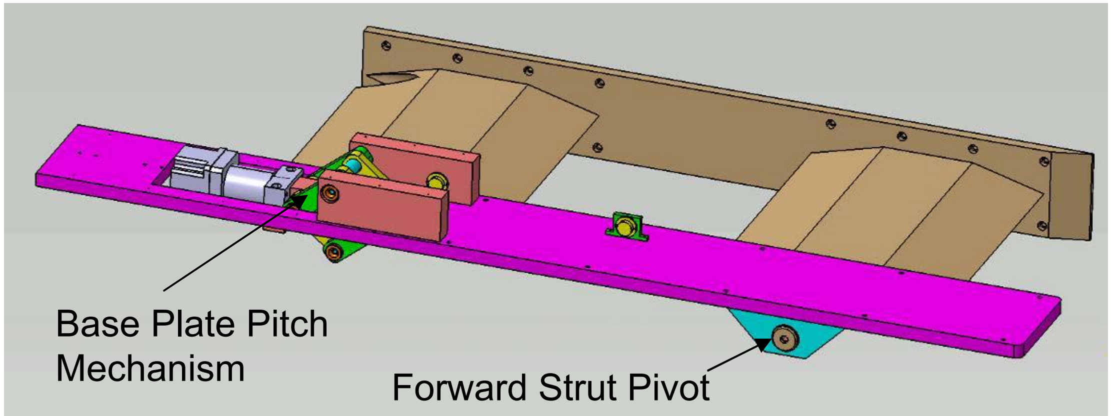
Width X Height = 4 ft X 4 ft

UPWT TS2 Mach Number Range: 2.29 to 4.63

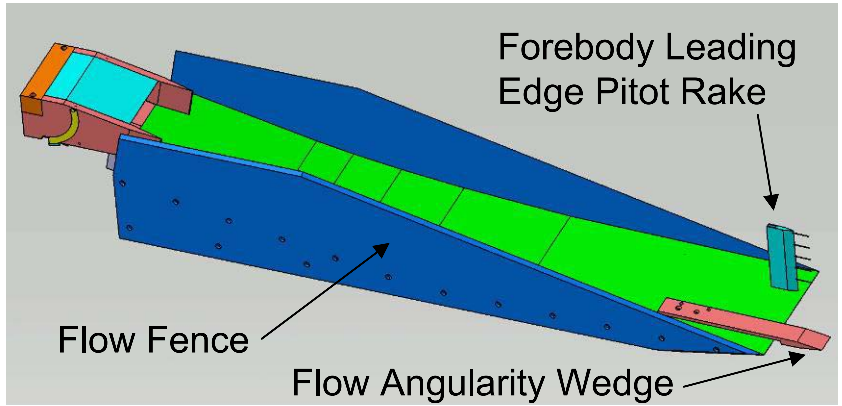


RTC Inlet Model Description

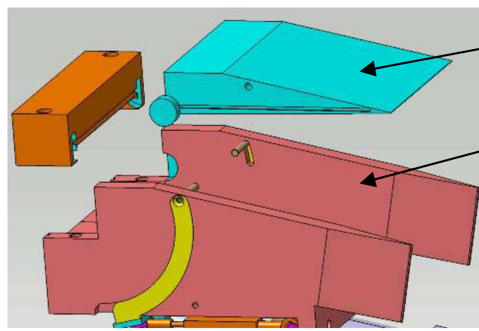




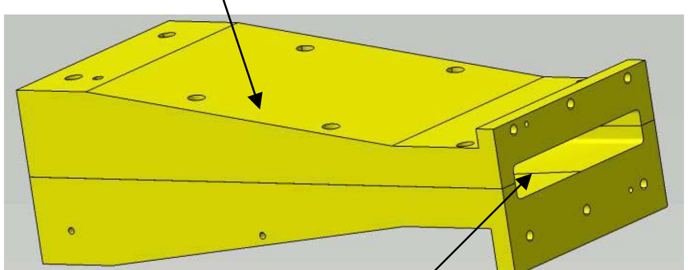
RTC Inlet Model Description (Continued)

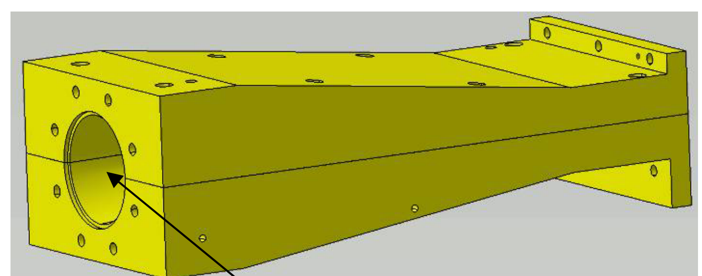


Note: Number 36 BL transition grit applied to the forebody, inlet sidewall, and cowl leading edges (internal only).



Isolator Clam Shell Design



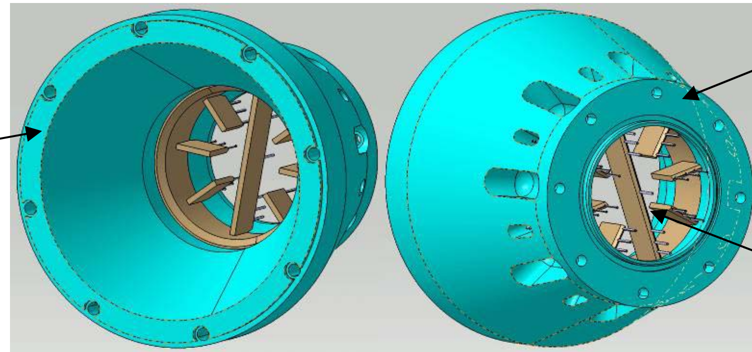


Isolator Entrance

Isolator Exit

RTC Inlet Model Description (Continued)

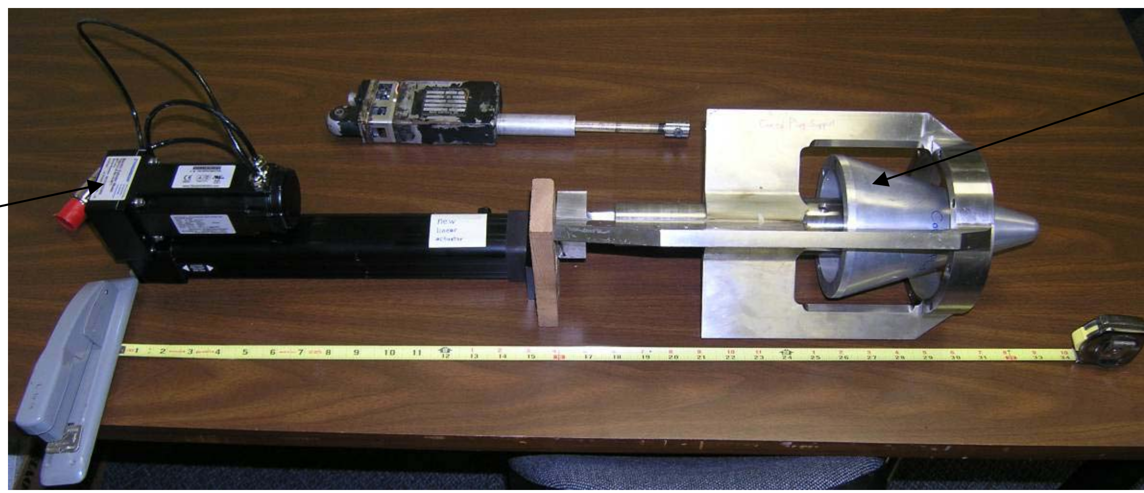
MFP Adapter Exit



Mass Flow Plug (MFP) Adapter, Entrance

Isolator Exit Pitot Rake

MFP Linear Actuator

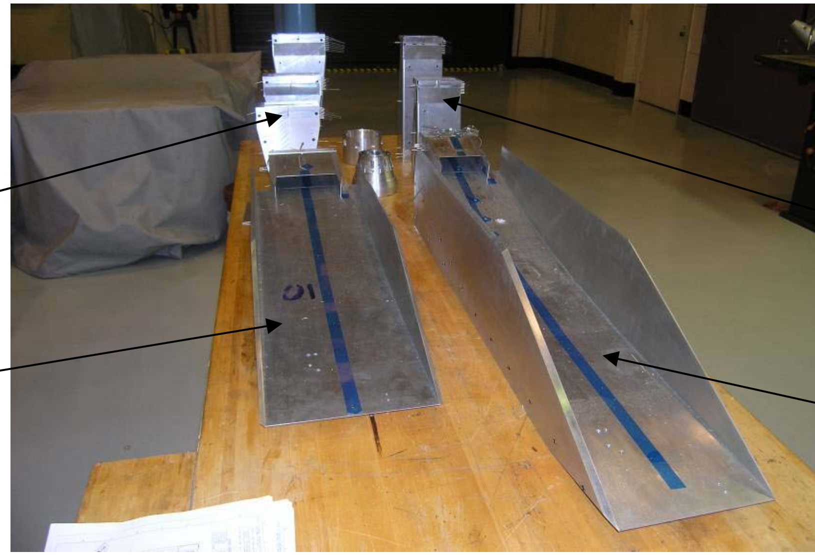


Conical MFP

RTC Inlet Model Configurations

AR10 Isolators

AR10 Forebody/Inlet



AR6 Isolators

AR6 Forebody/Inlet

RTC Inlet Model Actuators and Controllers

Cowl Flap Motor

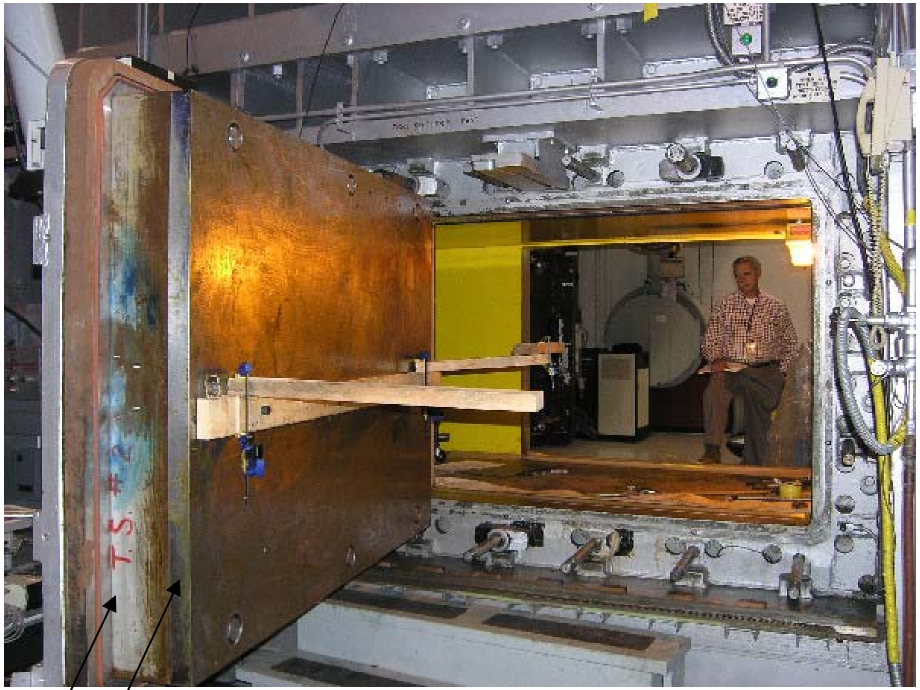
Base Plate Motor

IDC Controller for MFP Actuator and Elmo Controller for Cowl Flap and Base Plate Pitch System

Model Instrumentation

- 145 model surface static pressure measurements (5 and 45 psid ESP modules)
- 10 model surface dynamic pressure measurements (100 psia Kulites)
- 10 FAW surface static pressures measurements (5 psid ESP module)
- 34 pitot rake pressure measurements (45 psid ESP module)
- 2 thermocouples to monitor the temperature of the ESP modules
- 2 electronic inclinometers (Seika N-series by Rieker Electronics)
- 1 conical MFP to measure the inlet mass capture

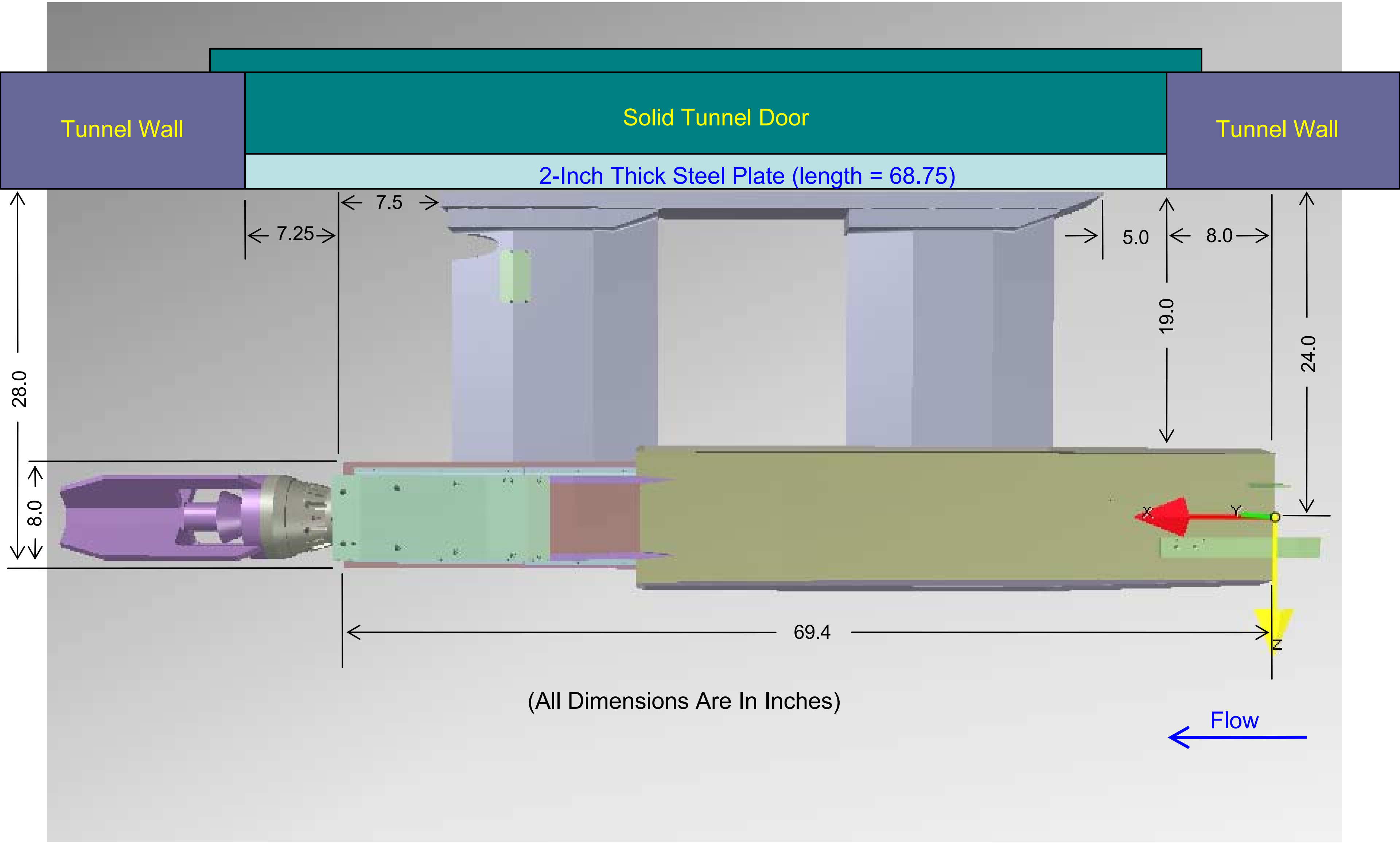
Installation: Solid Tunnel Door



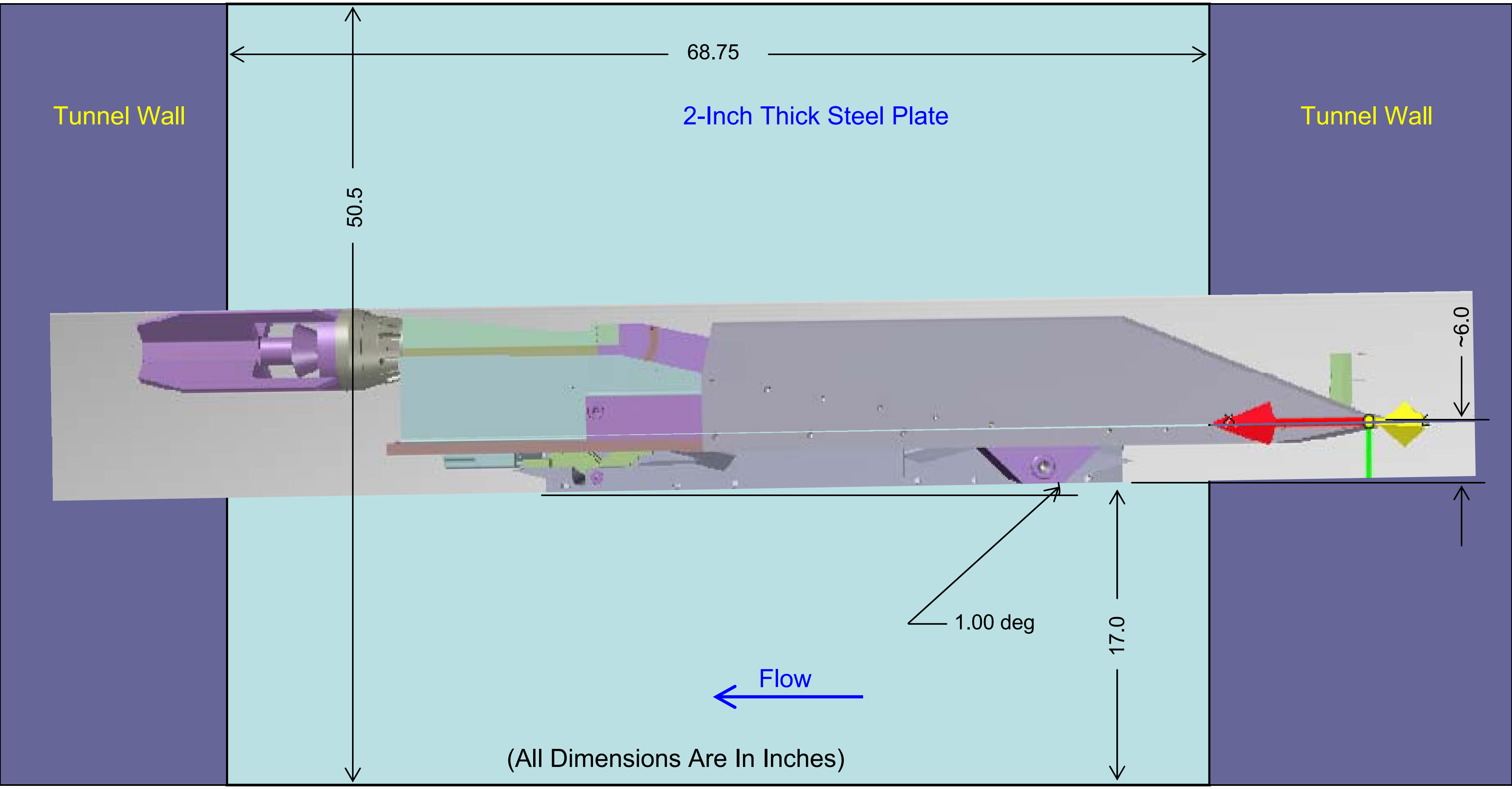
2-Inch Thick Steel Plate

Solid Tunnel Door

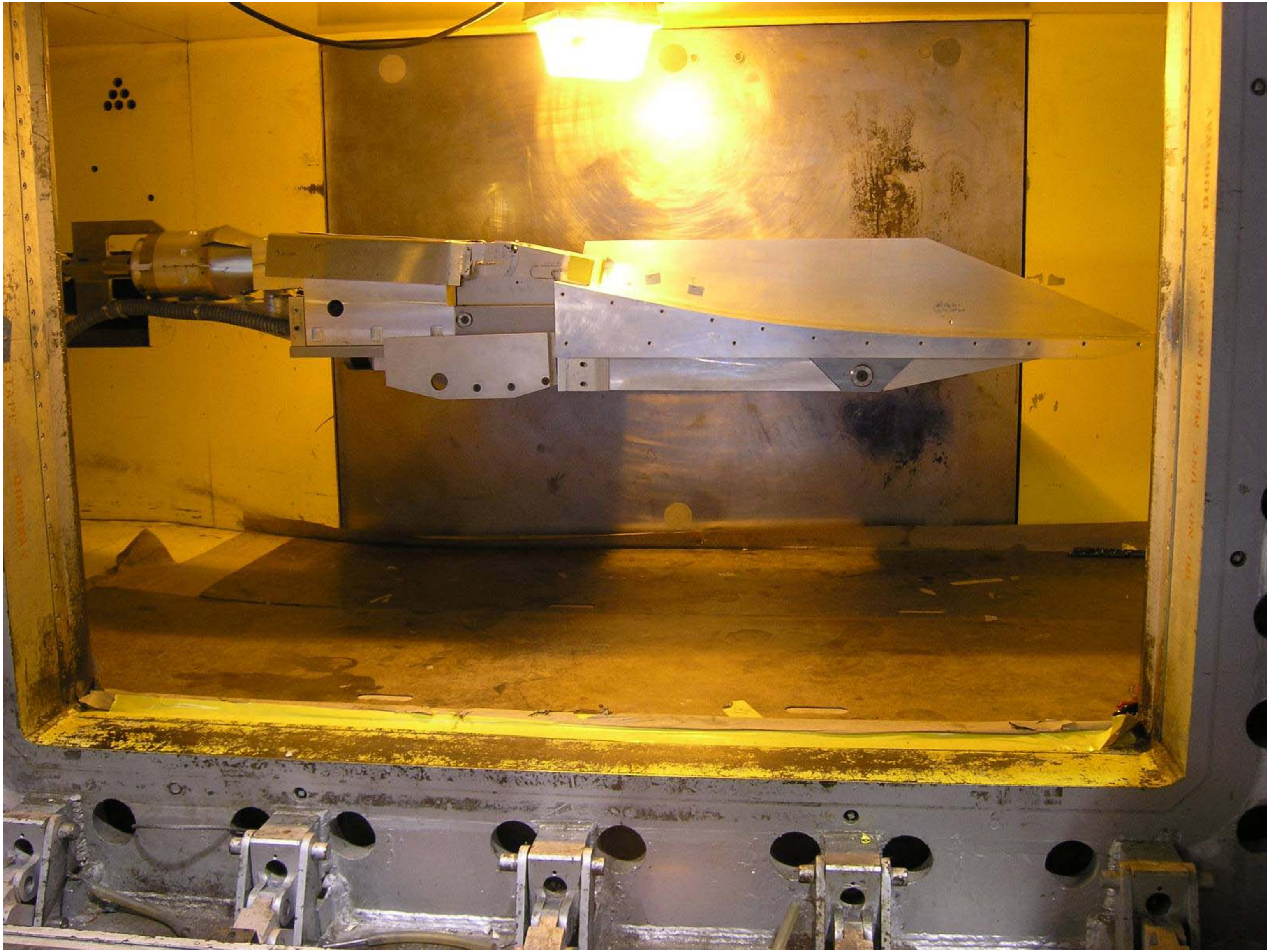
Installation: RTC Inlet Model (Top View)



Installation: RTC Inlet Model (Side View)

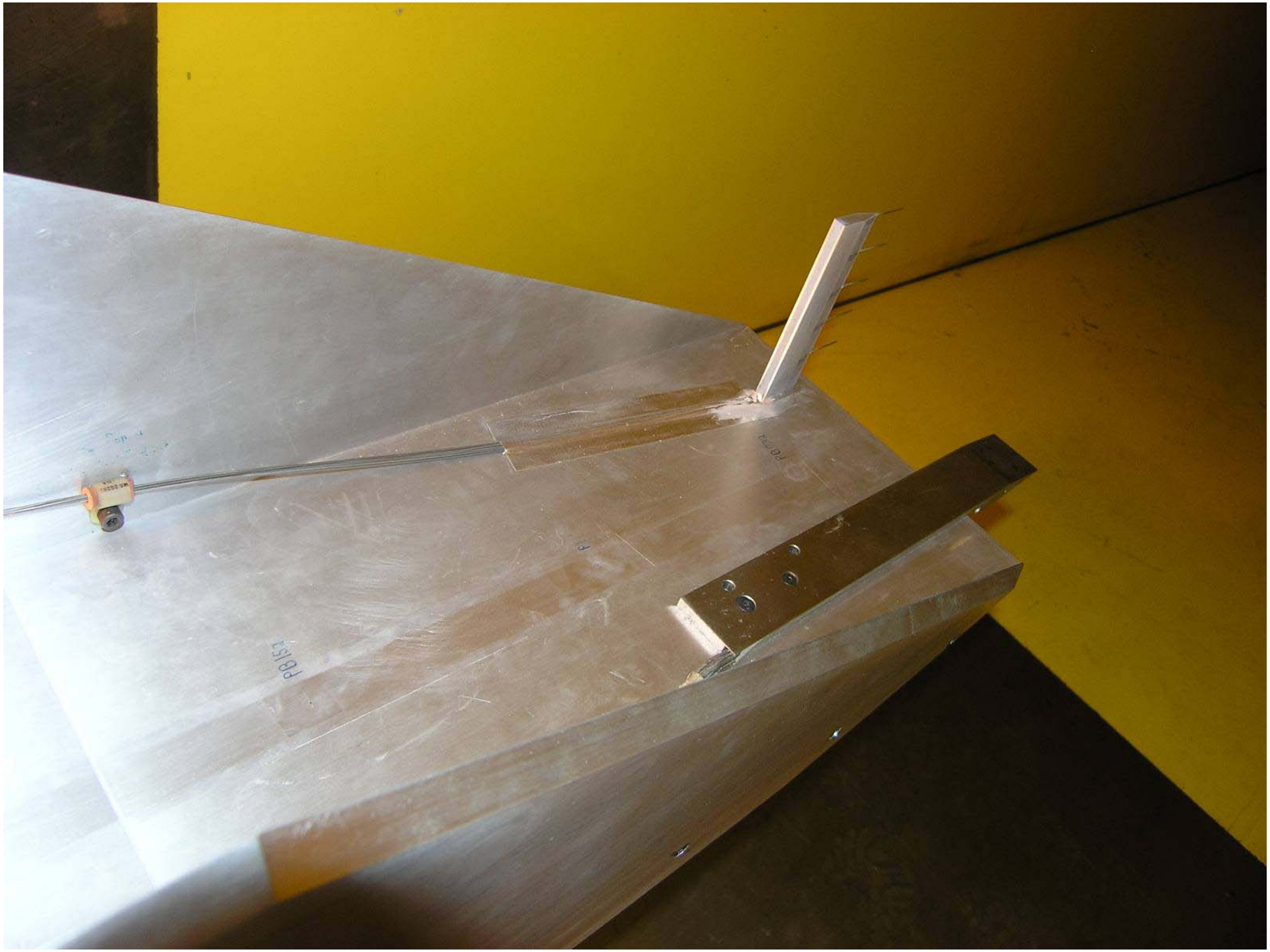


AR6 RTC Inlet Configuration

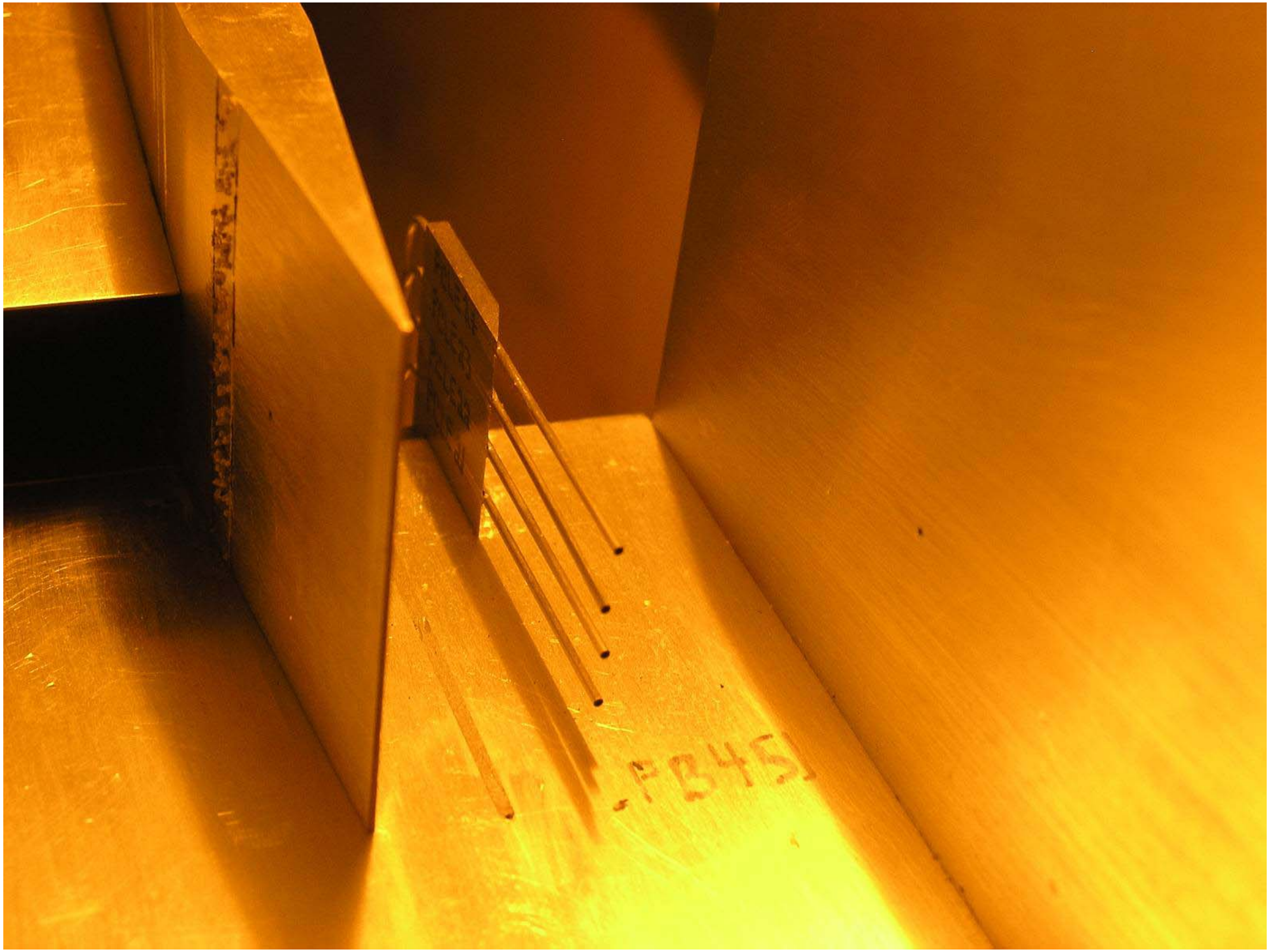


AR6 RTC Inlet Configuration

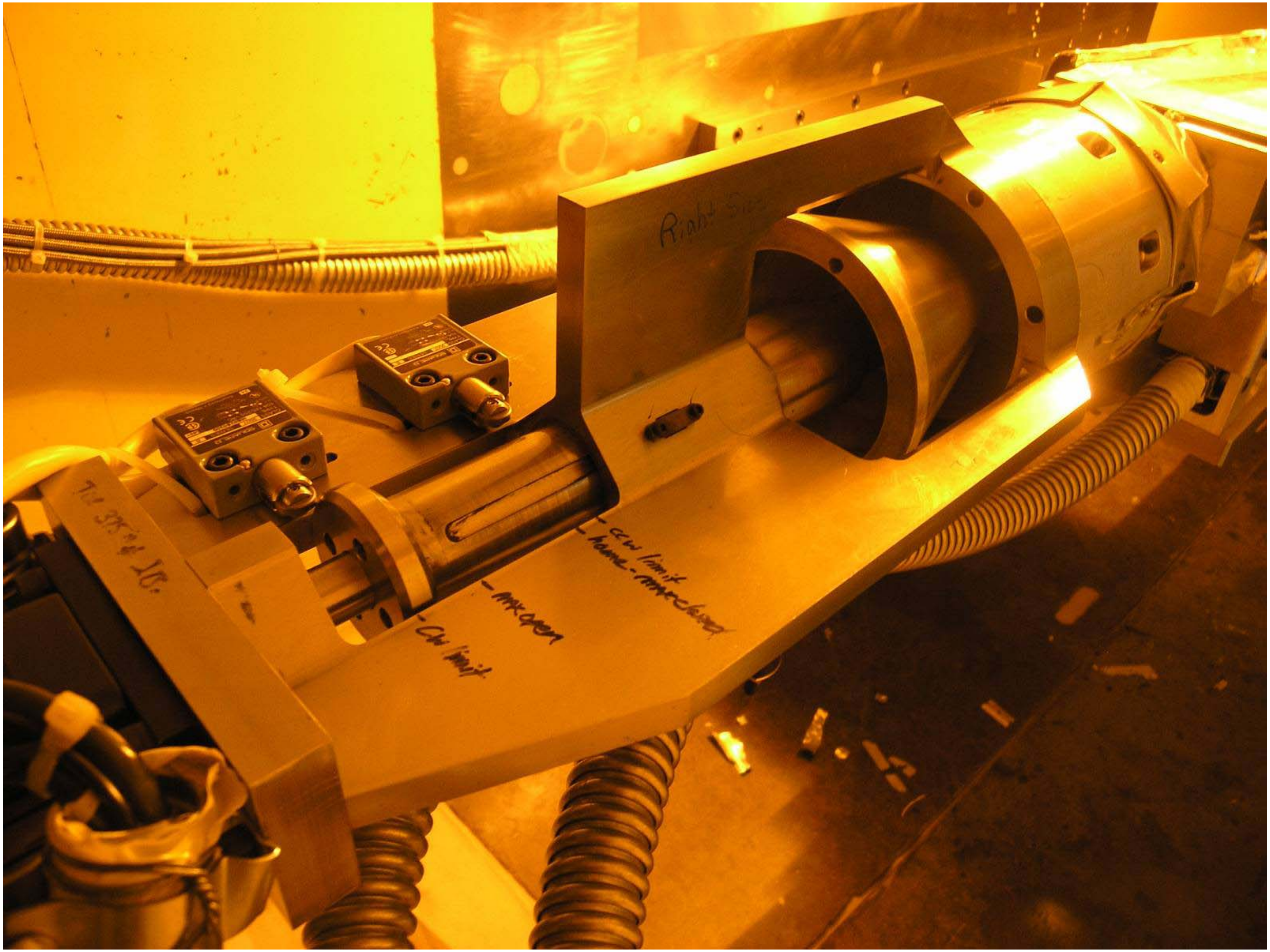
Flow Angularity Wedge and FBLE Rake



Inlet Plane Survey Rake



Conical Mass Flow Plug



AR10 RTC Inlet Configuration

RTC Inlet Model Presentation for 2007 NASA FAP Meeting in New Orleans

Test Program

Simulated Flight and UPWT Test Conditions for the RTC Inlet Model

Simulated Vehicle Flight Conditions			UPWT Freestream Test Conditions for 25% Scale Model					
Mach	Re/ft (X 10^6)	AOA (deg)	Mach	Re/ft (X 10^6)	T_t (deg F)	AOA (deg) of 1st FB Ramp	P (psia)	T (deg R)
2.5	1.13	4.0	2.29	4.50	150.0	0.0	1.934	297.6
3.0	1.25	4.0	2.75	5.00	150.0	0.0	1.338	242.7
3.5	1.25	4.0	3.20	5.00	150.0	0.0	0.866	200.2
4.0	1.25	4.0	3.64	5.00	150.0	0.0	0.578	167.0
4.5	1.25	4.0	4.07	5.00	150.0	0.0	0.398	141.4
5.0	1.35	4.0	4.49	5.40	150.0	0.0	0.304	121.2

Configuration Identification Codes for the RTC Inlet Model Test in UPWT

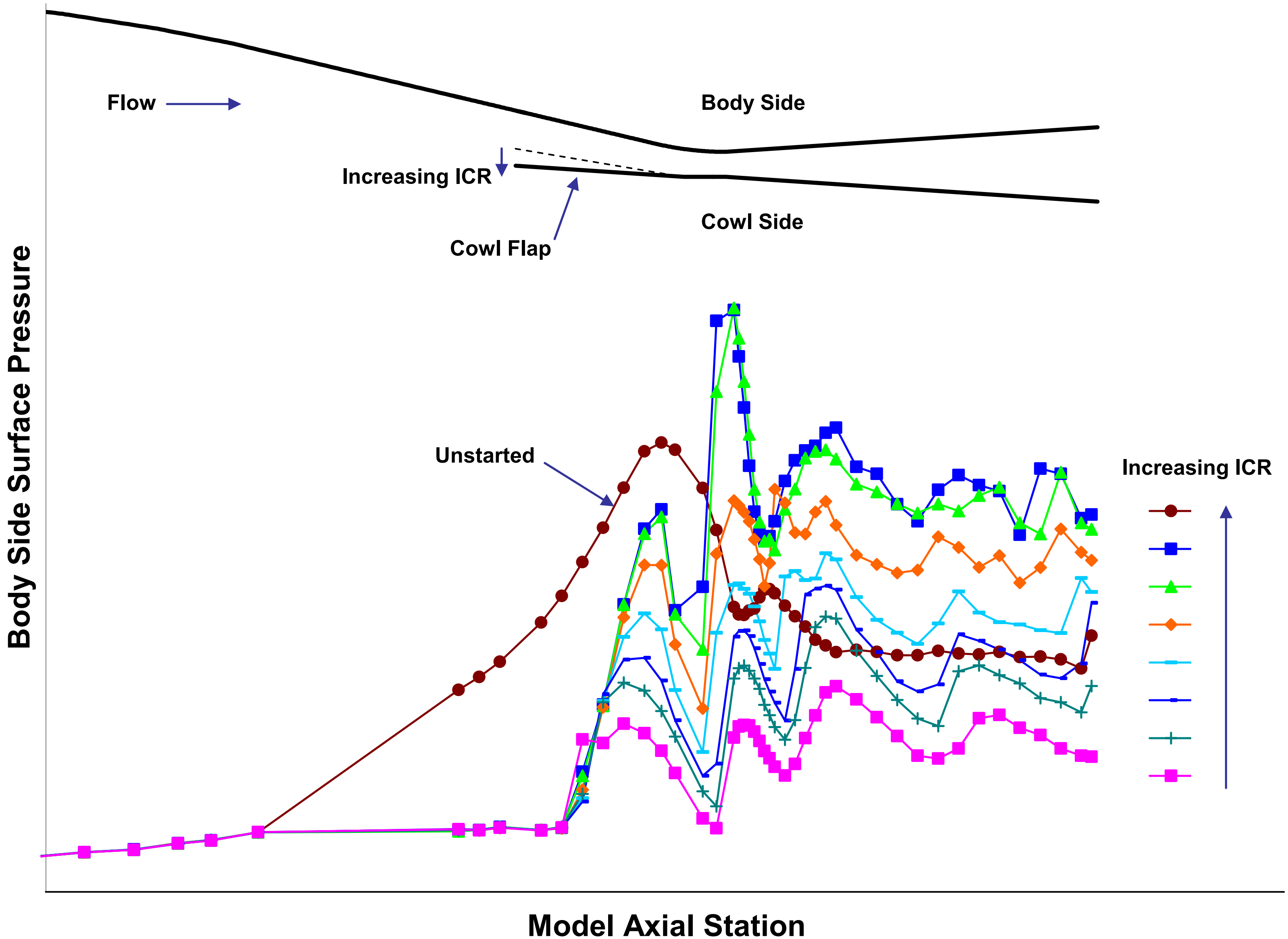
ID	Configuration Code	Forebody (FB)	Inlet	Isolator	FB LE Rake	Flow Angularity Wedge	CLE Rake
C100	AR6LOD8FA	AR6	AR6	LOD8	YES	YES	NO
C101	AR6LOD8	AR6	AR6	LOD8	NO	NO	YES
C102	AR6LOD6	AR6	AR6	LOD6	NO	NO	YES
C103	AR10LOD8	AR10	AR10	LOD8	NO	NO	YES
C104	AR10LOD6	AR10	AR10	LOD6	NO	NO	YES
C105	AR10LOD5	AR10	AR10	LOD5	NO	NO	YES

Run Event Sequence for RTC Inlet Model Test in UPWT

1. Set target facility Mach number and then set model pitch to adjust for flow angularity (aligns model first ramp with tunnel flow).
2. Conduct an incremental cowl flap angle sweep increasing ICR until the ICR inlet unstart limit is determined (single point data acquisition).
3. Conduct a continuous cowl flap angle sweep increasing ICR until the inlet unstarts (continuous data acquisition) and then sweep the cowl flap closed to determine the self-start restart limit.
4. Set the cowl flap to a fixed angle below the unstart limit and conduct an isolator back pressure incremental sweep by translating the conical MFP forward until the back pressure inlet unstart limit is determined (single point data acquisition).
5. Repeat the isolator back pressure sweep with a continuous conical MFP motion and with (continuous data acquisition).

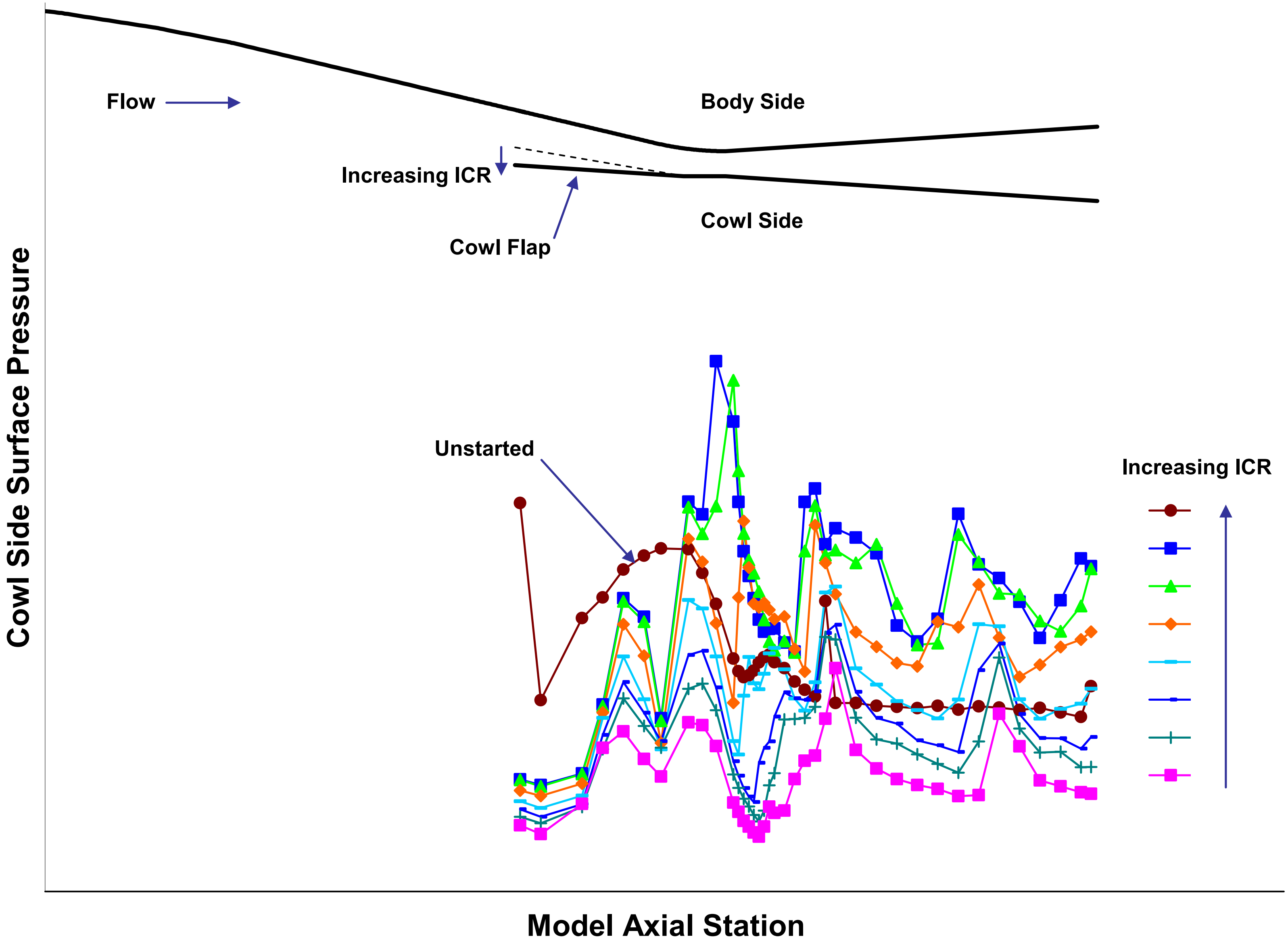
Body Side Pressure Distribution Variation with Cowl Flap Angle

(Determination of the ICR Operability Limit for AR6LOD6, Mach =4.49, no Back Pressure)



Cowl Side Pressure Distribution Variation with Cowl Flap Angle

(Determination of the ICR Operability Limit for AR6LOD6, Mach =4.49, no Back Pressure)



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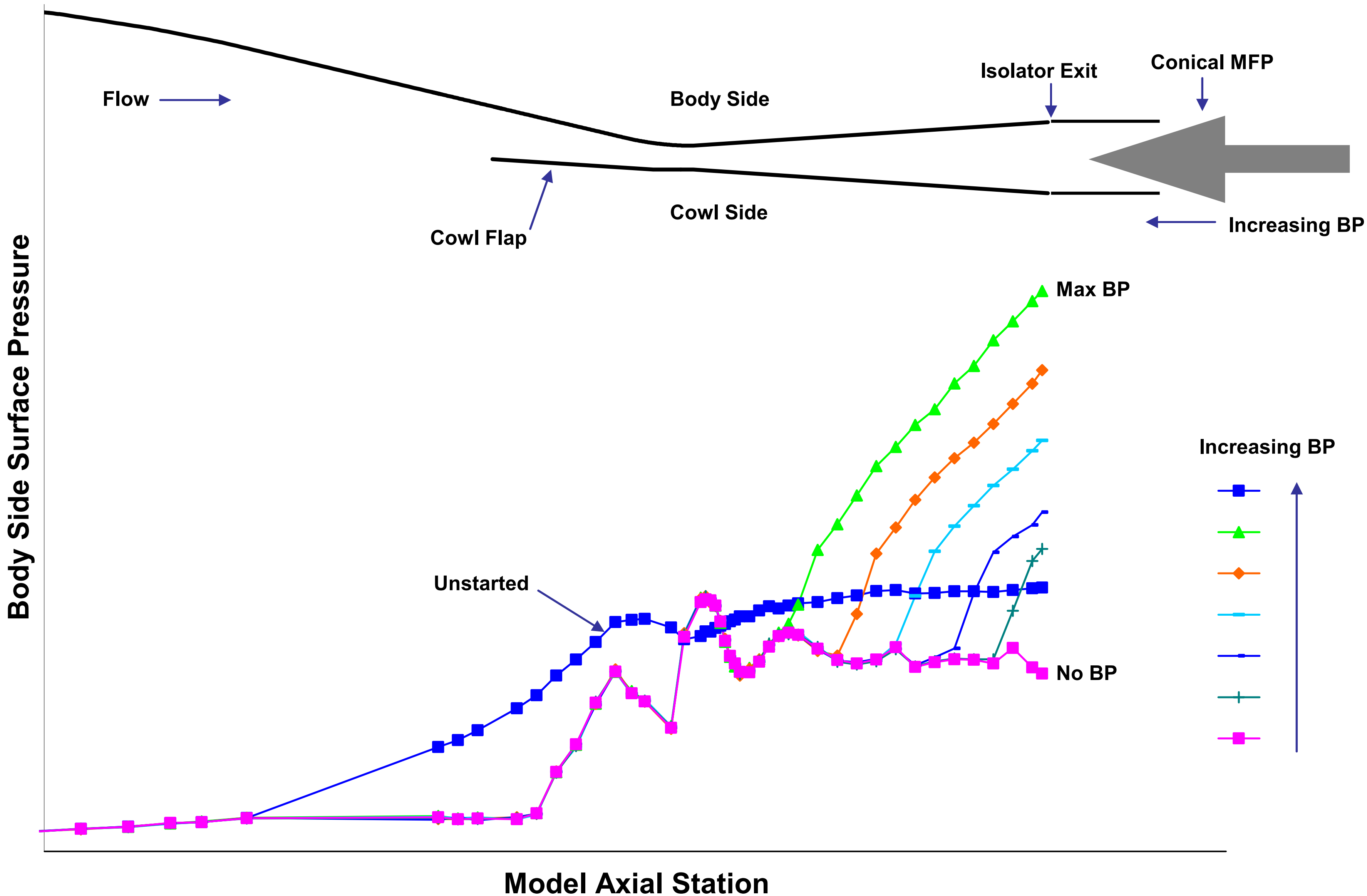
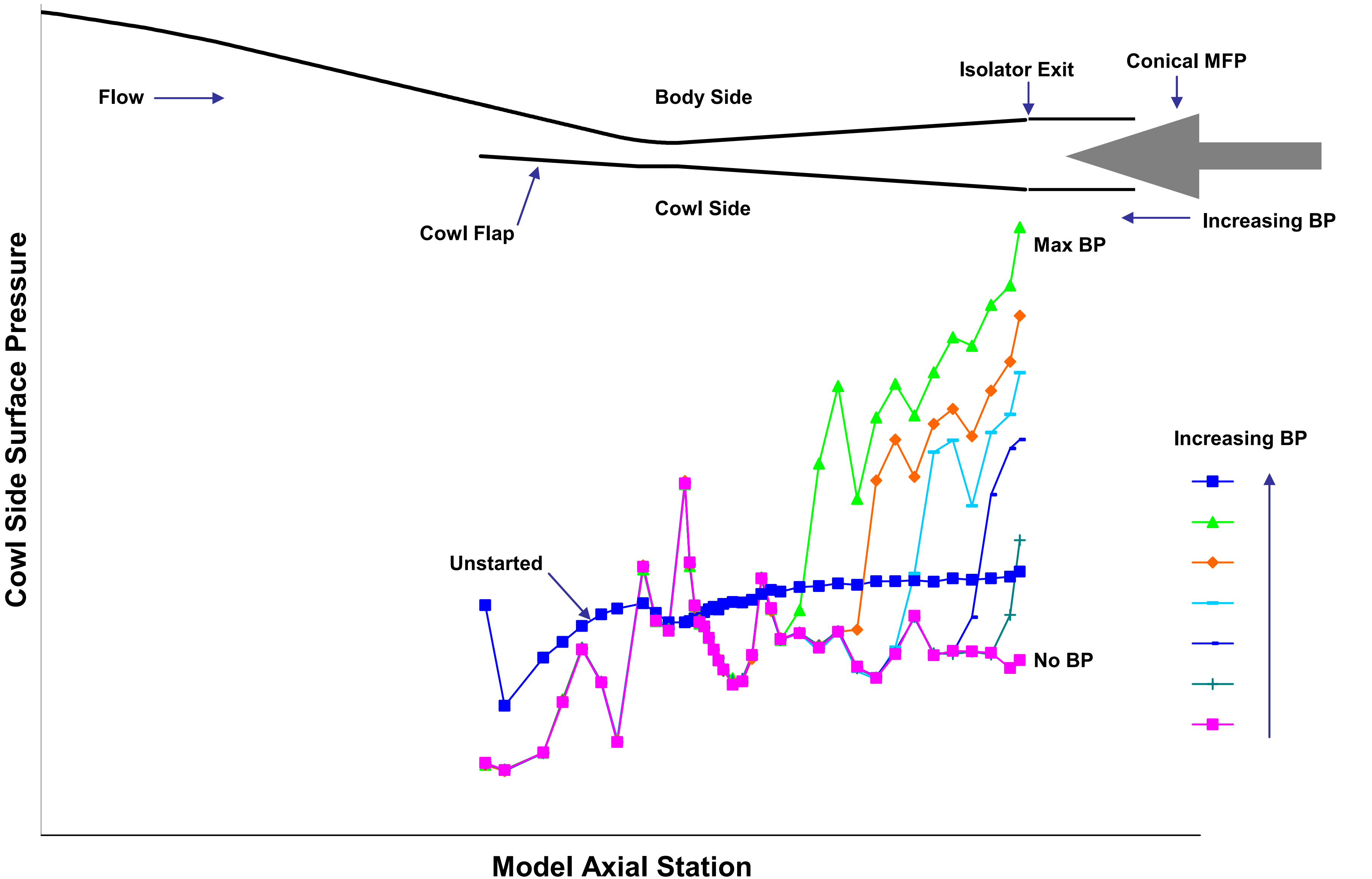
Body Side Pressure Distribution Variation with Back Pressure

(Determination of the BP Operability Limit for AR6LOD6, Mach =4.49, Max ICR)



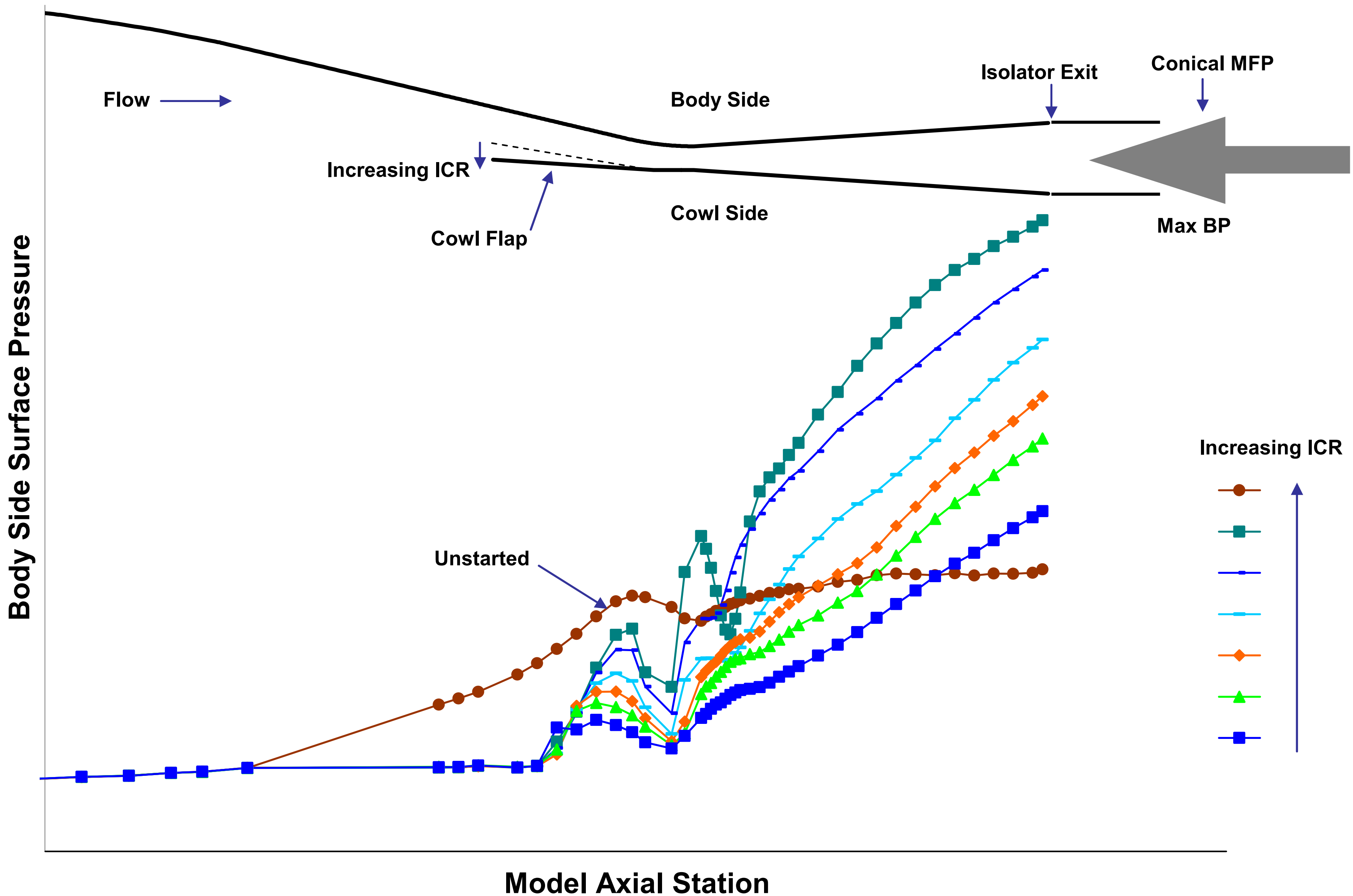
Cowl Side Pressure Distribution Variation with Back Pressure

(Determination of the BP Operability Limit for AR6LOD6, Mach =4.49, Max ICR)



Body Side Pressure Distribution Variation with Cowl Flap Angle

(Determination of the ICR Operability Limit for AR6LOD6, Mach =4.49, with Back Pressure)



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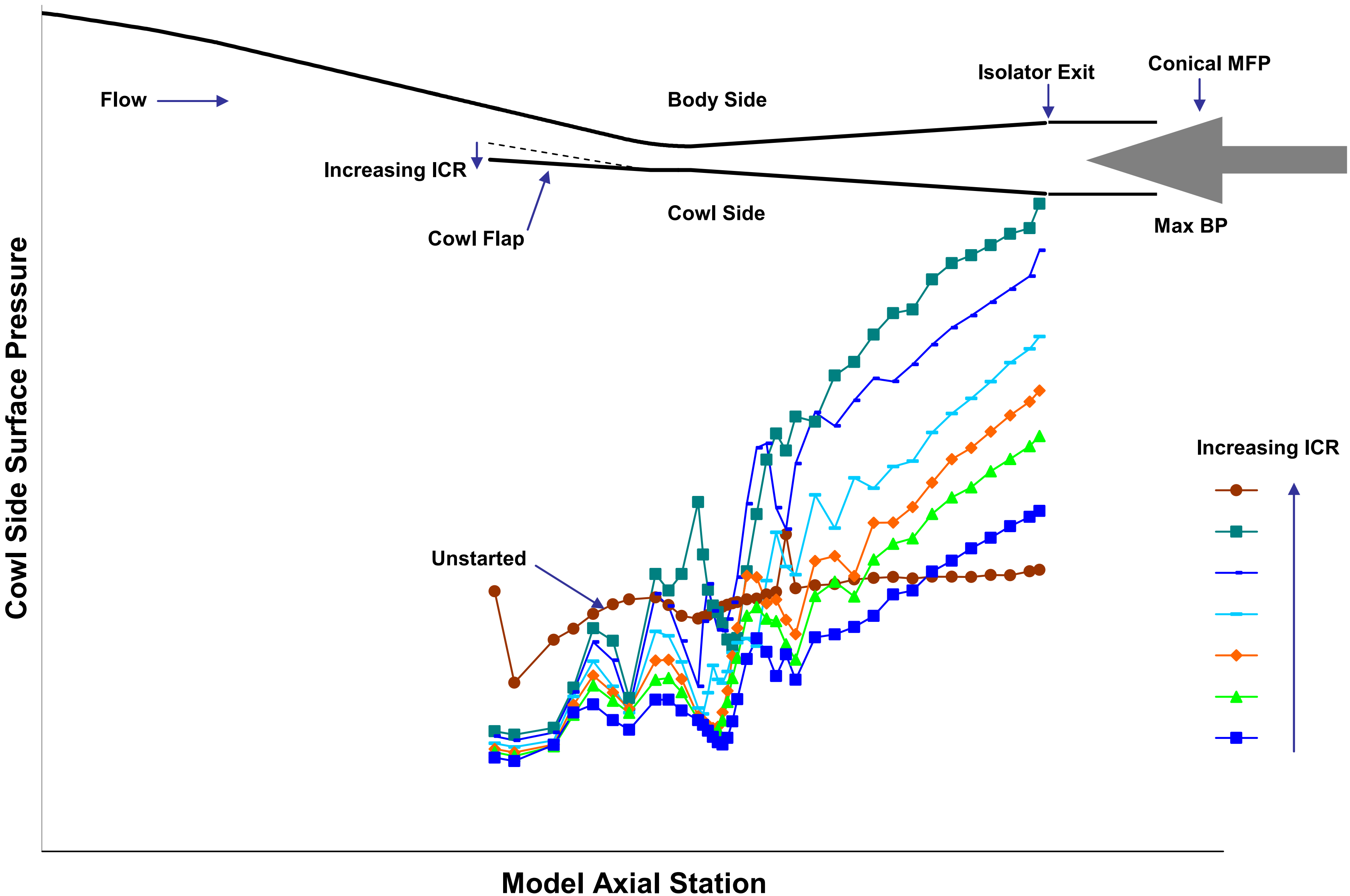
Cowl Side Pressure Distribution Variation with Cowl Flap Angle

(Determination of the ICR Operability Limit for AR6LOD6, Mach =4.49, with Back Pressure)



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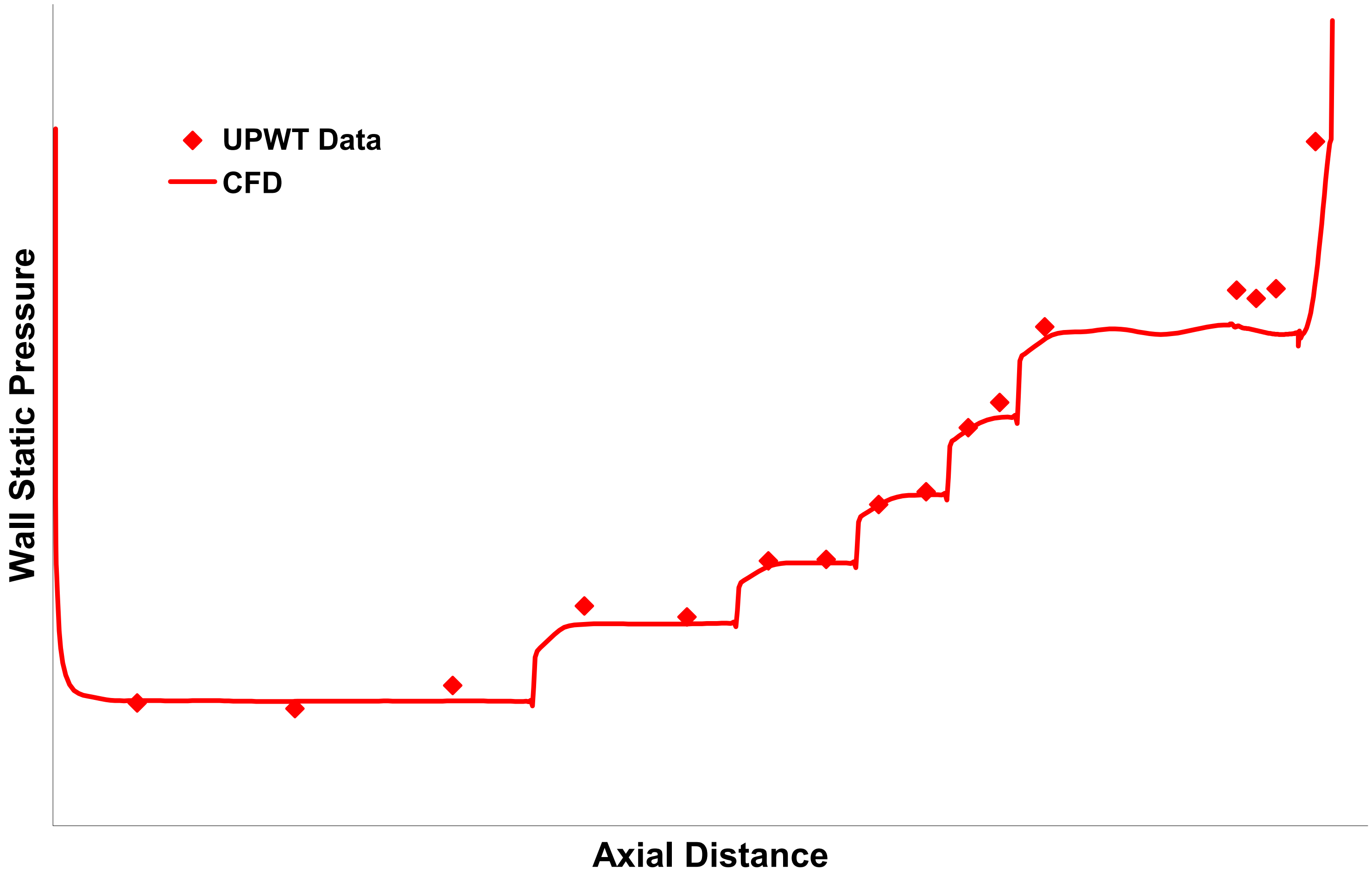
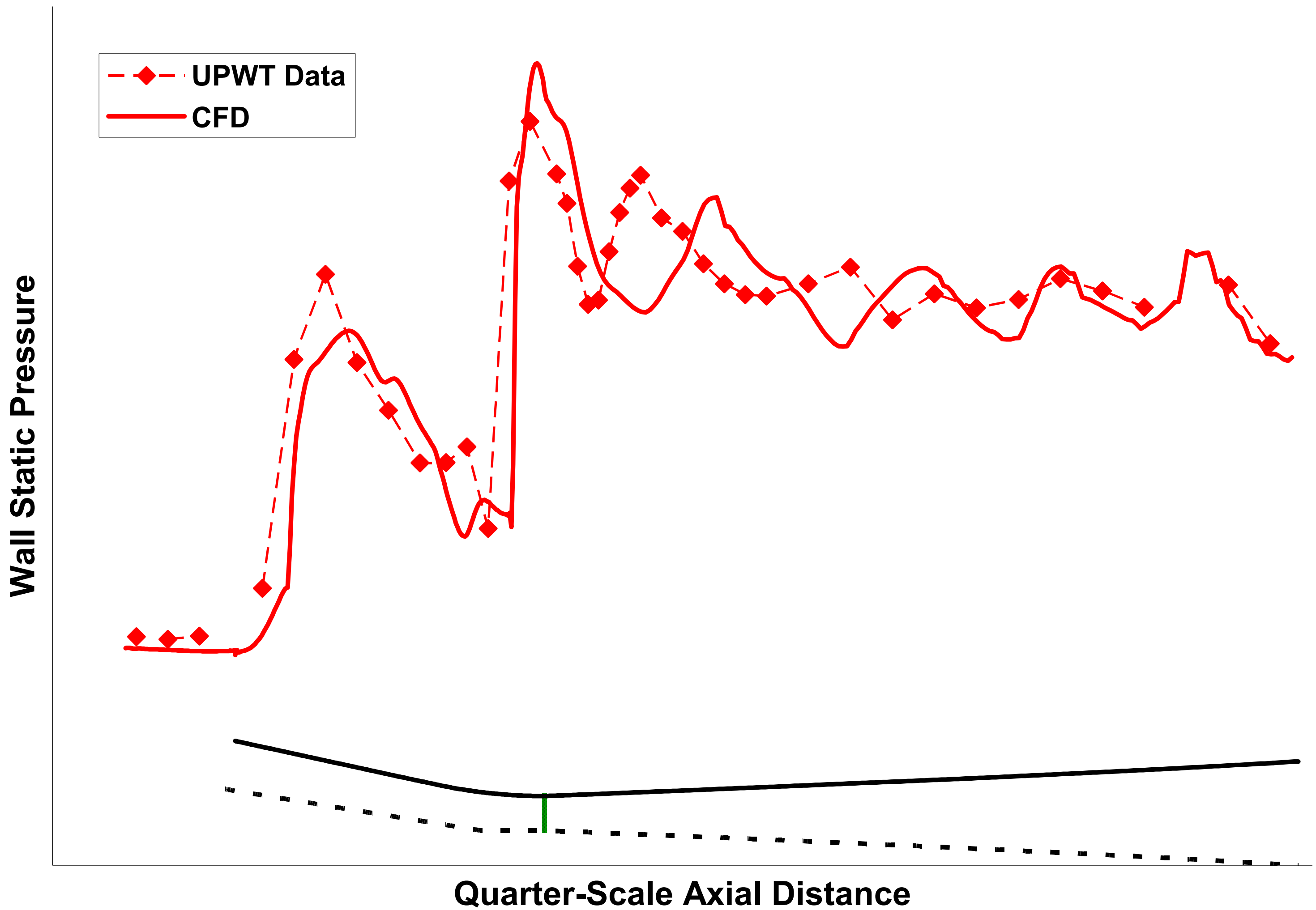
Forebody Pressure Distribution: Pretest CFD vs. UPWT Data

(AR6LOD8, Mach = 3.20, no Back Pressure)



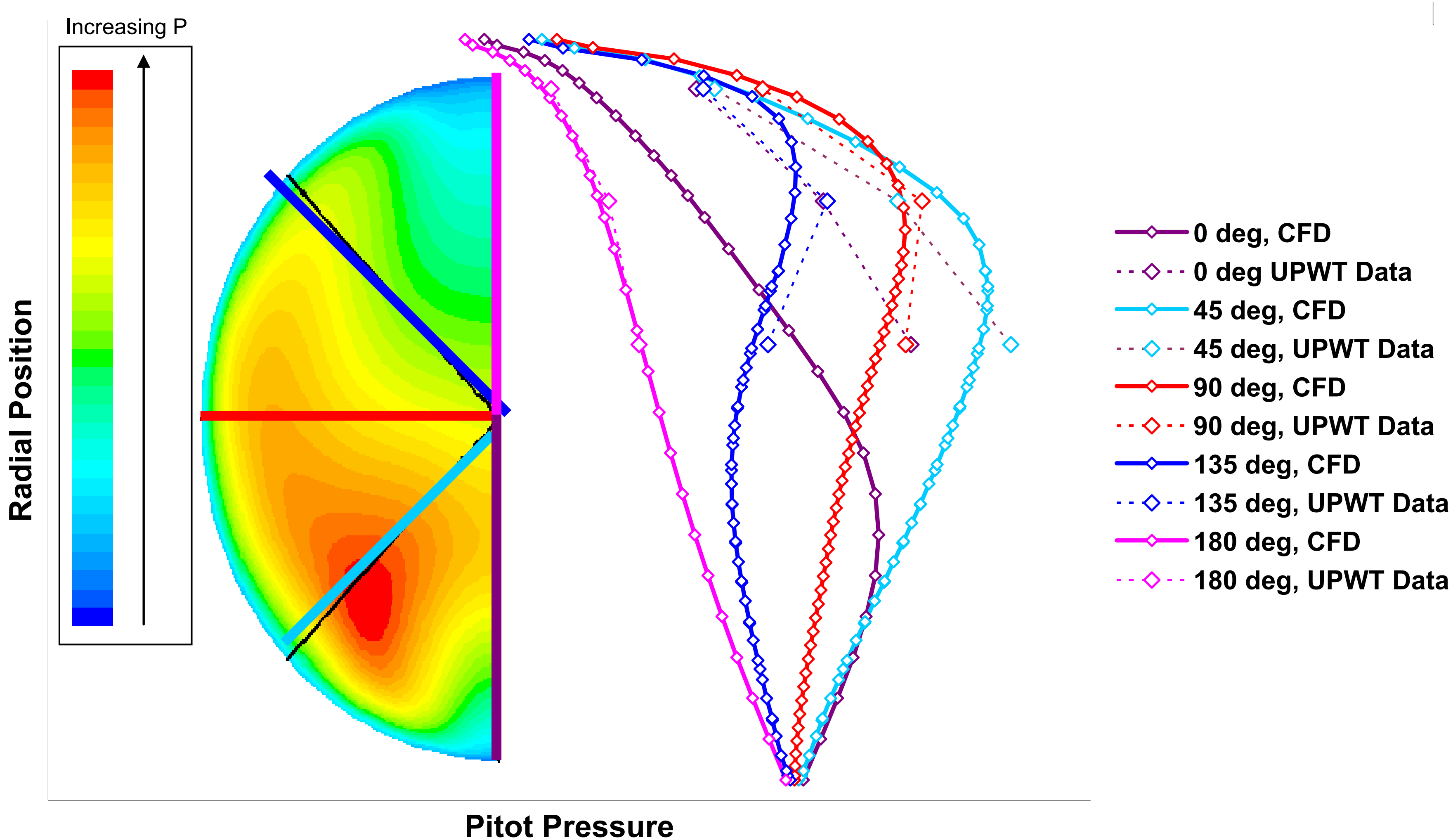
Body Side Internal Pressure Distribution: Pretest CFD vs. UPWT Data

(AR6LOD8, Mach = 3.20, no Back Pressure)



Isolator Exit Pitot Pressure Profile: Pretest CFD vs. UPWT Data

(AR6LOD8, Mach = 4.49, no Back Pressure)



RTC Inlet Model Research Status

- UPWT test of the RTC Inlet Model completed on August 31, 2007.
  - 373 runs (ICR or isolator back pressure sweeps)
  - Over 2500 data points (unique test conditions: Mach/Re number, ICR, isolator back pressure, and model configuration)

- UPWT dataset analysis in progress
  - Experimental data analysis ongoing at NASA Langley and Alliant Techsystems
  - Pre-test CFD to data comparison performed by Alliant Techsystems
  - Post-test CFD to data comparison planned by Alliant Techsystems, NASA Langley, and NASA Glenn
  - Post-test data comparison to 1D distortion analysis isolator model planned by NASA Langley

- Preliminary UPWT RTC Inlet Model test assessment:
  - Pre-test CFD agrees with forebody surface pressure data (within 5 percent)
  - The forebody flow fences need to be modeled in the post-test CFD
  - Pre-test CFD captures inlet shock structure although a phase lag is apparent in pressure data
  - Pre-test CFD shows reasonable agreement with the isolator wall pressure level and the highly three-dimensional isolator exit flow survey data